

# Lawrence Livermore National Laboratory



## Introduction – Definition of the Basic Questions for this FUSHE2012 Workshop

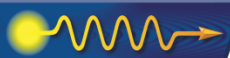
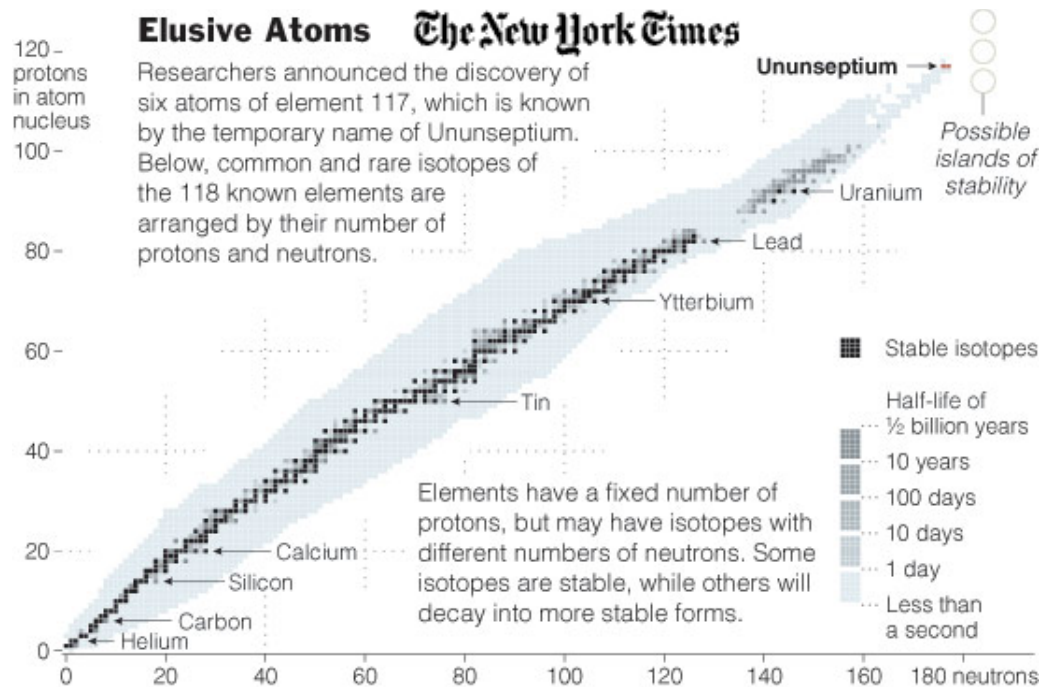


**Mark A. Stoyer**

**May 13, 2012**

# Discovery of a new element is as fascinating to the public as landing on the moon (or Mars)

**“The question we’re trying to answer is, ‘Does the periodic table come to an end, and if so, where does it end?’ ”**  
**Kenton Moody -- LLNL**



# The chemistry of an element, and its adherence or lack thereof to periodicity, is a fundamental scientific question

Period 1    Periodic Table 1-172    18 Orbitals

1	1 H	2														13	14	15	16	17	2 He	1s
2	3 Li	4 Be										5 B	6 C	7 N	8 O	9 F	10 Ne	2s2p				
3	11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	3s3p			
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	4s3d4p			
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	5s4d5p			
6	55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	6s5d6p			
7	87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113	114	115	116	117	118	7s6d7p			
8	119	120	121-	156	157	158	159	160	161	162	163	164	139	140	169	170	171	172	8s7d8p			
9	165	166											167	168						9s9p		

Elements  
for which  
no chemical  
info known

6	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	4f			
7	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	5f			
8	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	6f			
8	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	5g

Elements  
don't have  
to fit into  
the  
periodic  
table in this  
way!



# How many more elements are there?

Periodic Table 1-172

1	2											13	14	15	16	17	18	Orbitals
1	2																	1s
3	4											5	6	7	8	9	10	2s2p
Li	Be											B	C	N	O	F	Ne	
11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	3s3p
Na	Mg											Al	Si	P	S	Cl	Ar	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	4s3d4p
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	5s4d5p
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	6s5d6p
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	7s6d7p
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn							
119	120	121-	156	157	158	159	160	161	162	163	164	139	140	169	170	171	172	8s7d8p
165	166											167	168				9s9p	

W. Nazarewicz APS April Meeting 2012, Atlanta, GA

*“Half of chemistry is still undiscovered. We don't know what it looks like and that's the challenge”*

6	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	4f
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
7	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	5f
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	
8	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	6f

The limit of mass and charge is still undiscovered. We don't know what it looks like and that's the challenge.

8	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	5g
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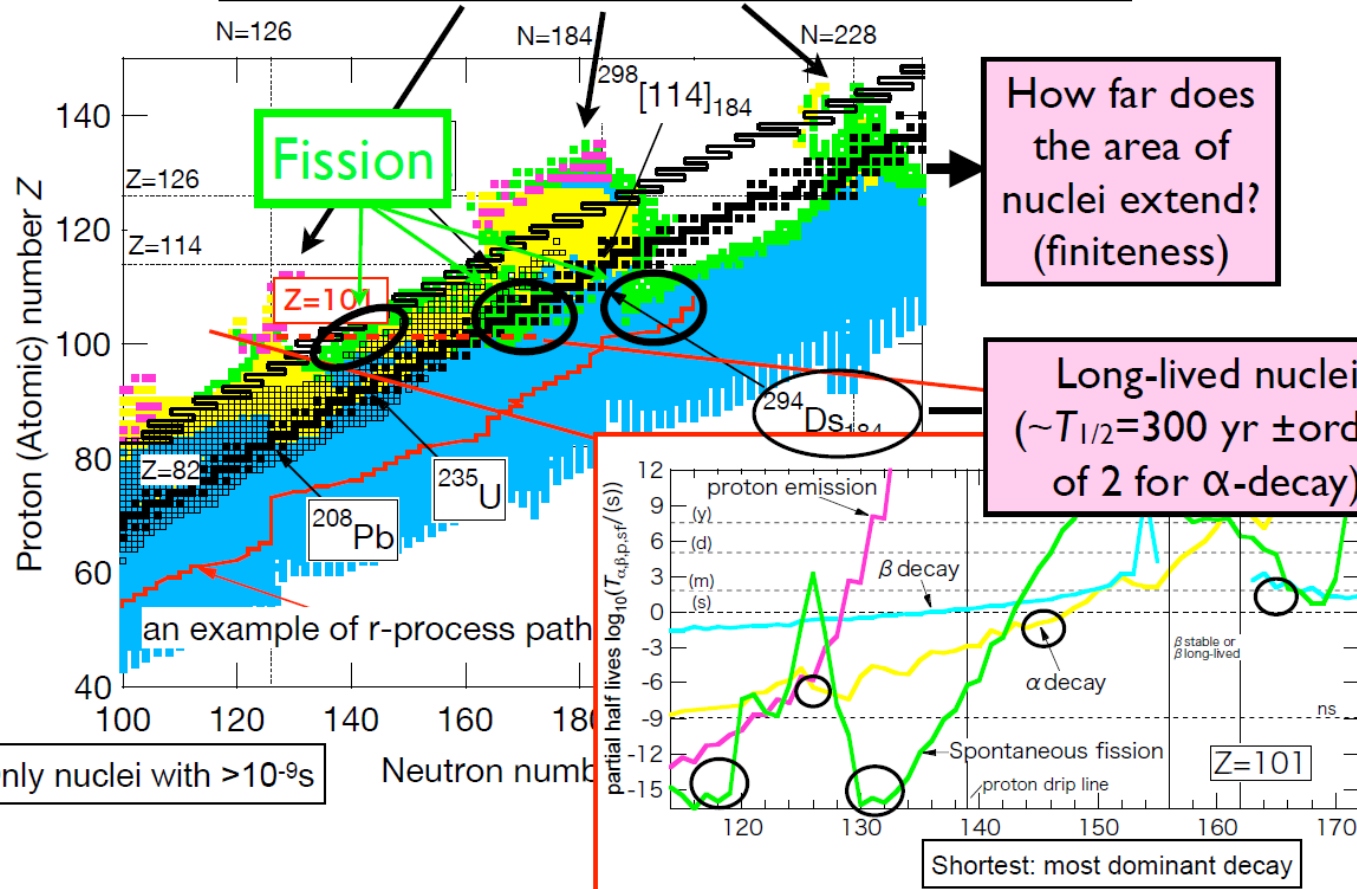


# Just exactly where are the next closed shells and how many nucleons can be bound together in a nucleus?

## Decay modes in the superheavy region

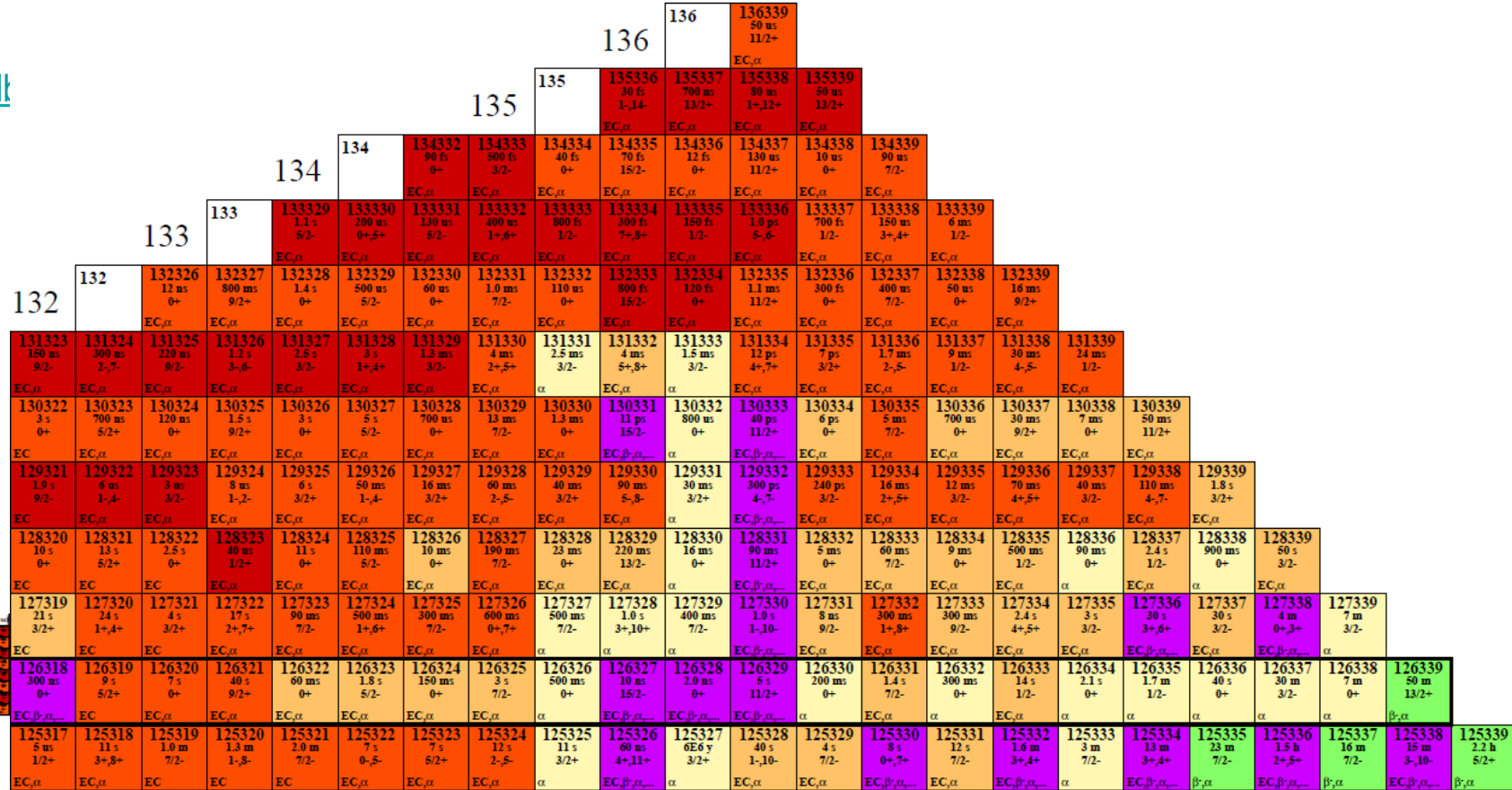
How does nuclear closed shell periodicity go on?

H. Koura, Fourth International Conference on Fission and Properties of Neutron-Rich Nuclei Nov. 11-17, 2007, Sanibel Island, FL, USA



# Another version of decay properties predicted for heavy isotopes

<http://ie.ll>



Moller Theoretical Nuclear Chart (1997) Z=88-136

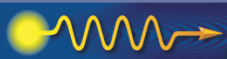
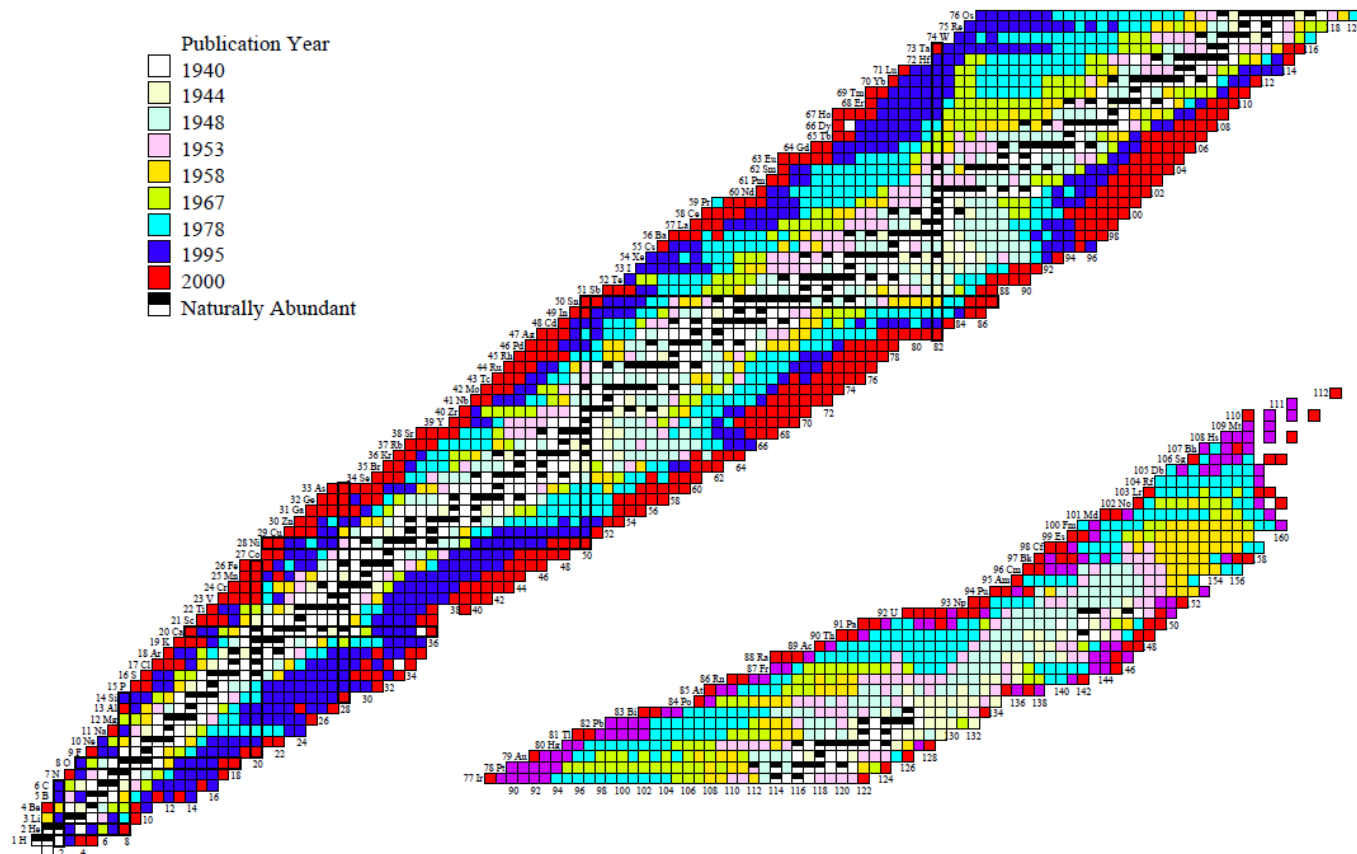
*Properties for Astrophysical Applications* by P. Moller, J.R. Nix, and K.-L. Kratz, LA-UR-94-3898(1994).

- $Q(\beta^-) - S_n > 0$
- $Q(\beta^-) > 0 + Q(EC) > 0$
- Stable to Beta Decay
- $Q(EC) > 0$
- $Q(EC) - S_p > 0$
- $Q(p) > 0$
- Naturally Abundant
- $S_n < 0$

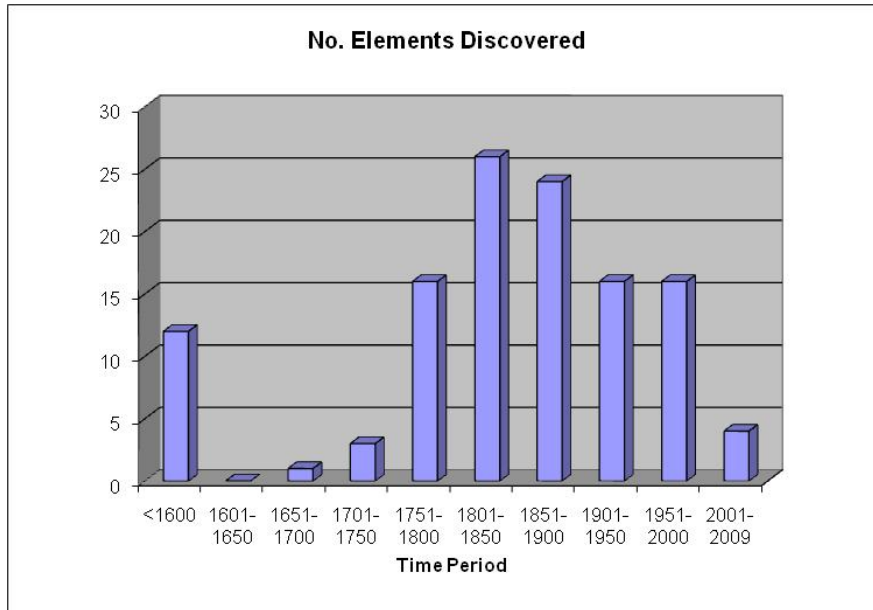
# History of the discovery of isotopes

<http://ie.lbl.gov/systematics/history00.pdf>

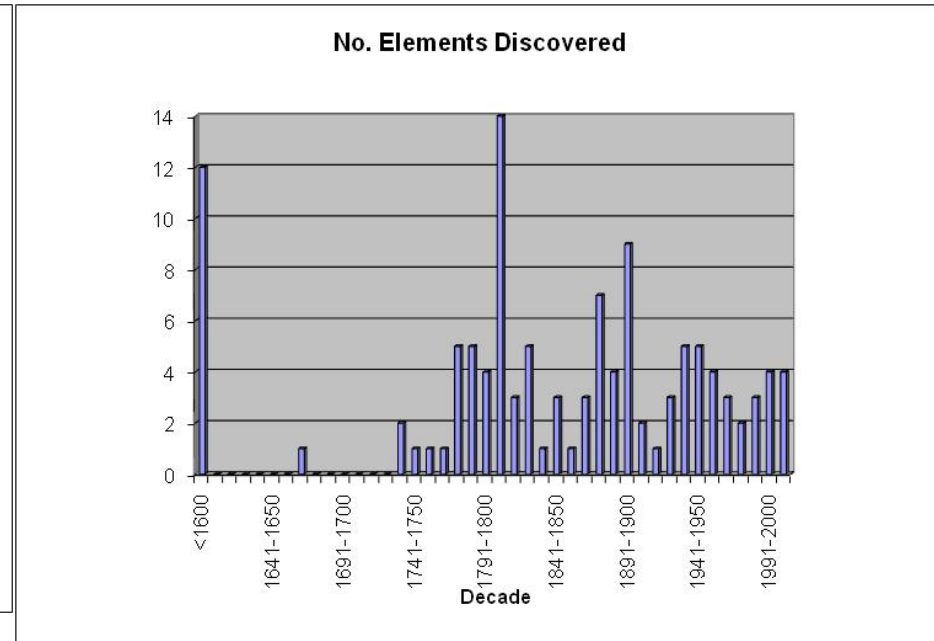
## Evolution of the *Table of Isotopes*



# New element discovery has progressed steadily since the 1700's



**On average, just under 20 elements have been discovered every half-century**



**On average, about 4 elements have been discovered every decade**





# FUSHE 2012 - Topics and Goal

- Experiment
- Theory
- Instrumentation

## **Goal:**

***Discuss and define the (near and far) future strategy for the field of SHE research***

## **Experiment**

- **Z- and A identification of the isotopes produced in  $^{48}\text{Ca}$ -induced reactions on actinide targets**
- **Single particle trends towards the gap of the spherical SHE**
- **Ground state properties (e.g. masses)**
- **Decay properties (fission barriers, lifetimes) of SHE**
- **Chemical properties**
- **Reaction mechanism**
- **Collective properties/in beam spectroscopy**

# FUSHE 2012 - Topics

- Experiment
- Theory
- Instrumentation

## *Goal:*

*Discuss and define the (near and far) future strategy for the field of SHE research*

## Theory

- Spherical and deformed shell gaps, density profiles, stabilization mechanisms (shell, vibrational etc.).
- Structure of ground and low-lying excited states of SHN: energies, spins, parities, transition strengths, isomerism
- Evolution of ground state shapes and fission barriers as function of Z and A, and limits of the region of SHE
- Excitation energy dependence of fission barriers
- Evolution of di-nuclear systems: contact to capture, fusion-fission, deep-inelastic collision etc.
- Energy transfer, dissipation-fluctuation dynamics in nuclear reactions.
- A review of the relevant models and guidance for future experiments.
- SHE quantum chemistry
- Astrophysical relevance for SHE

# FUSHE 2012 - Topics

- Experiment
- Theory
- Instrumentation

## **Goal:**

***Discuss and define the (near and far) future strategy for the field of SHE research***

## **Instrumentation**

- High intensity stable beam accelerator
- High current/low energy target development
- New separators (S3, M/Q- or other mass selection/spectroscopy)
- Detector development
- Inbeam spectroscopy/target (gammas, electrons,...)
- Decay spectroscopy/after separation (ERs, alphas, gammas, electrons, X-rays)
- Electronics (digital, pulse shape analysis,...)
- Ion traps
- Laser spectroscopy
- Chemistry instrumentation (gas-jet transport system; ion-exchange, solvent extraction, electro-chemistry apparatuses; gas-chemistry apparatuses; chemistry apparatus coupled to recoil separators, detectors coupled to chemistry apparatus)

# FUSHE 2012 - Session Organisation

## Sessions

- The **three main categories** will be combined under various topics such as nuclear structure or synthesis, which will be wrapped up in a final discussion for each **“theme”**.
- The “themes” should, where possible, consist of contributions from the three main categories.
- The sessions will be guided by **discussion leaders** who will **extract strategic ideas, milestones** etc.
- The outcome of the various sessions will be put together in a **final strategy paper** representing the basis for the **common strategy of the SHE community** brought together in the workshop.

# The workshop is organized into sessions that cut across experiment, theory and instrumentation

- Monday morning – SHE synthesis
- Monday afternoon, continuing to Tuesday morning – heavy and SHE nuclear structure
- Tuesday afternoon – chemistry of the heaviest elements
- Wednesday morning – SHE unified and novel aspects
- Wednesday afternoon – final discussions with conclusions

# FUSHE 2012 - Venue



The ***Conference&Sports Hotel Erbismühle*** is located in a nice valley, the *Weital*, in the *Taunus hills* about 50 km north of Frankfurt (50 km to Frankfurt main station and 55 km to Frankfurt airport) close to the *village Weilrod* in the centre of Germany.

The *Taunus hills* have formed the northern border of the Roman Empire and traces of it can still be visited today like the rebuilt Roman Castle *Saalburg* together with a few meters of the *limes*, the Roman border installations and defence line against the barbarians north of it...

# FUSHE 2012 - Organising Committee

D. Ackermann (chair – GSI)  
D. Boilley (co-chair – GANIL)  
Ch. Stodel (scientific secretary – GANIL)  
B. Avez (CENBG)  
M. Block (GSI)  
P. Greenlees (JYFL)  
K. Hauschild (CSNSM)  
D. Jacquet (IPNO)  
K. Jadambaa (GSI)  
E. Litvinova (GSI)  
R. Lozeva (IPHC)  
B. Sulignano (IRFU)

# FUSHE 2012 - Advisory Committee

M. Bender	CENBG, Bordeaux, France	France	6
J.P. Delaroche	CEA, Bruyères le Chatel, France	Germany	4
A. Drouart	IRFU, Saclay, France	Japan	3
J. Dudek	IPHC, Strasbourg, France	Finland	2
K. Eberhard	U. Mainz, Germany	Poland	2
H. Haba	RIKEN, Wako, Japan	U.S.A.	2
P.H. Heenen	U. Brussels, Belgium	Belgium	1
R.-D. Herzberg	U. Liverpool, U.K.	Russia	1
F.P. Heßberger	GSI, Darmstadt, Germany	U.K.	1
T. Khoo	ANL, Argonne, U.S.A.	Switzerland	1
H. Koura	JAEA, Tokai, Japan		
M. Leino	U. Jyväskylä, Finland		
K. Morita	RIKEN, Wako, Japan		
W. Nazarewicz	U. Knoxville, U.S.A.		
V. Pershina	GSI, Darmstadt, Germany		
H. Savajols	GANIL, Caen, France		
A. Sobiczewski	U. Warsaw, Poland		
Ch. Theisen	IRFU, Saclay, France		
A. Türler	PSI, Villigen and U. Bern, Switzerland		
J. Uusitalo	U. Jyväskylä, Finland		
A. Wieloch	U. Cracow, Poland		
A. Yakushev	GSI, Darmstadt, Germany	<i>Experiment</i>	<i>14</i>
V. Zagrebaev	JINR-FLNR, Dubna, Russia	<i>Theory</i>	<i>9</i>
		<b>Total</b>	<b>23</b>



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H. Haba	RIKEN, Wako, Japan	<b>Finland</b>	<b>2</b>
P.H. Heenen	U. Brussels, Belgium	<b>Poland</b>	<b>2</b>
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F.P. Heßberger	GSI, Darmstadt, Germany	<b>Belgium</b>	<b>1</b>
T. Khoo	ANL, Argonne, U.S.A .	<b>Russia</b>	<b>2</b>
H. Koura	JAEA, Tokai, Japan	<b>U.K.</b>	<b>1</b>
M. Leino	U. Jyväskylä, Finland	<b>Switzerland</b>	<b>1</b>
K. Morita	RIKEN, Wako, Japan		
W. Nazarewicz	U. Knoxville, U.S.A.		
H. Nitsche	LBNL, Berkeley, U.S.A.		
Yu.Ts. Oganessian	JINR-FLNR, Dubna, Russia	<b>Total</b>	<b>26</b>
V. Pershina	GSI, Darmstadt, Germany		
J. Roberto	ORNL, Oakridge, U.S.A.		
H. Savajols	GANIL, Caen, France		
A. Sobiczewski	U. Warsaw, Poland	<b>Experiment</b>	<b>17</b>
Ch. Theisen	IRFU, Saclay, France	<b>Theory</b>	<b>9</b>
A. Türler	PSI, Villigen and U. Bern, Switzerland		
J. Uusitalo	U. Jyväskylä, Finland		
A. Wieloch	U. Cracow, Poland		
A. Yakushev	GSI, Darmstadt, Germany		
V. Zagrebaev	JINR-FLNR, Dubna, Russia		

# FUSHE 2012 - Contact information

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Webpage: <http://www.ensarfp7.eu/workshops/fushe2012/>

# We will discuss many ideas for near and long term future developments in SHE, but I would urge “thinking big” also

- Surely, we will talk about incremental improvements in targets, accelerators, detection, etc., but what about an international accelerator dedicated to SHE synthesis and research?
- Surely, we will talk about improvements in theory, but what about a dedicated super-computer for SHE calculations?

**Challenge: Make one suggestion for long term future (10-20 years)**

# Unfortunately, we are one less person to make and execute this “Future of SHEs” plan



John Wild (1942-2012)

Memorial service planned for June 24, 2012

